

An Aerodynamic Simulation Process for Iced Lifting Surfaces and Associated Issues

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Outline

Effects of Ice on Aerodynamic Performance

Essential Elements of Icing Effects Study

A Simulation Process from Geometry to Solution

Issues in Geometry, Grid and Flow Solution

Geometry Acquisition

Blocking, Gridding, Merging

Flow Simulation

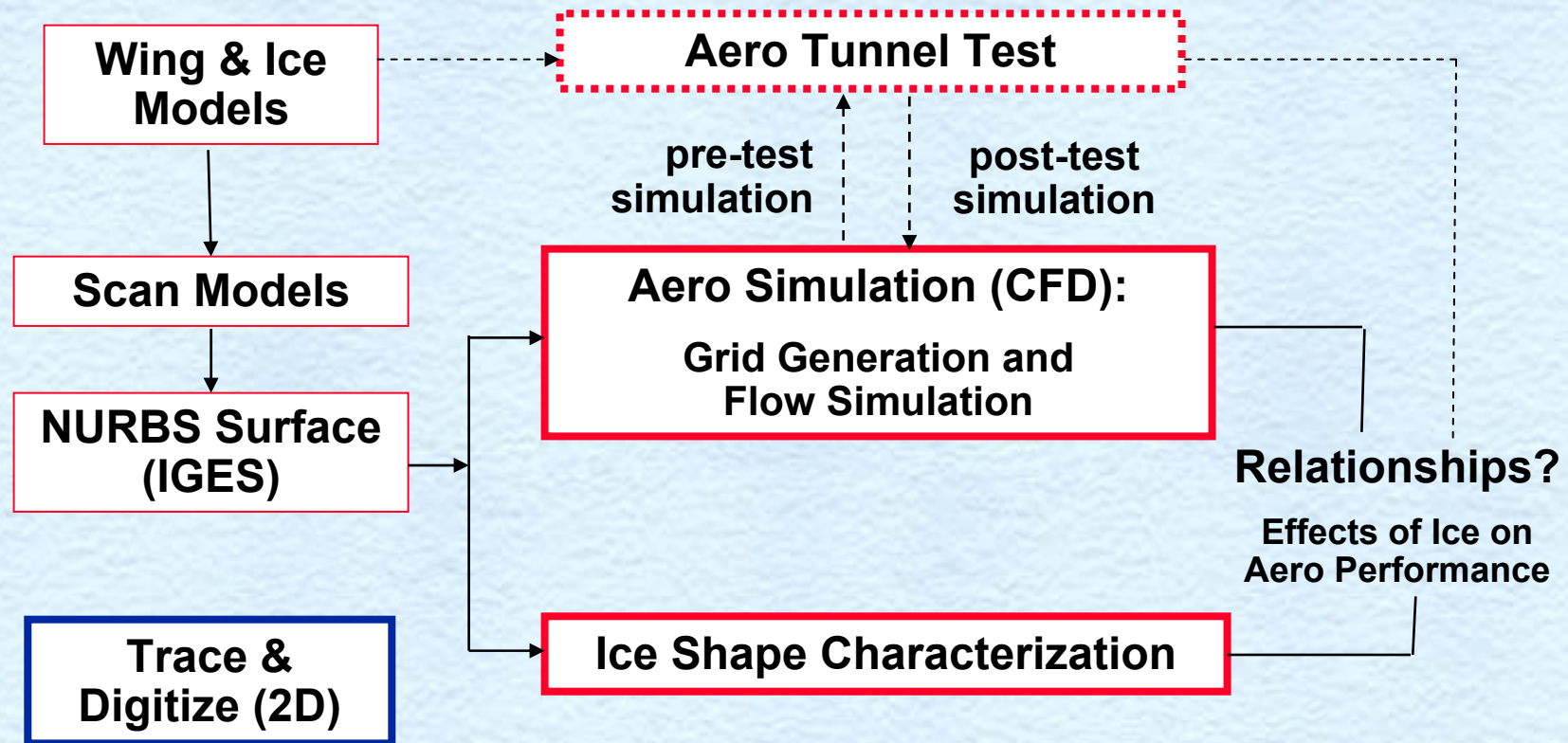
A Hypothesis

Most Conservative 3D Ice Shape (2D→3D)

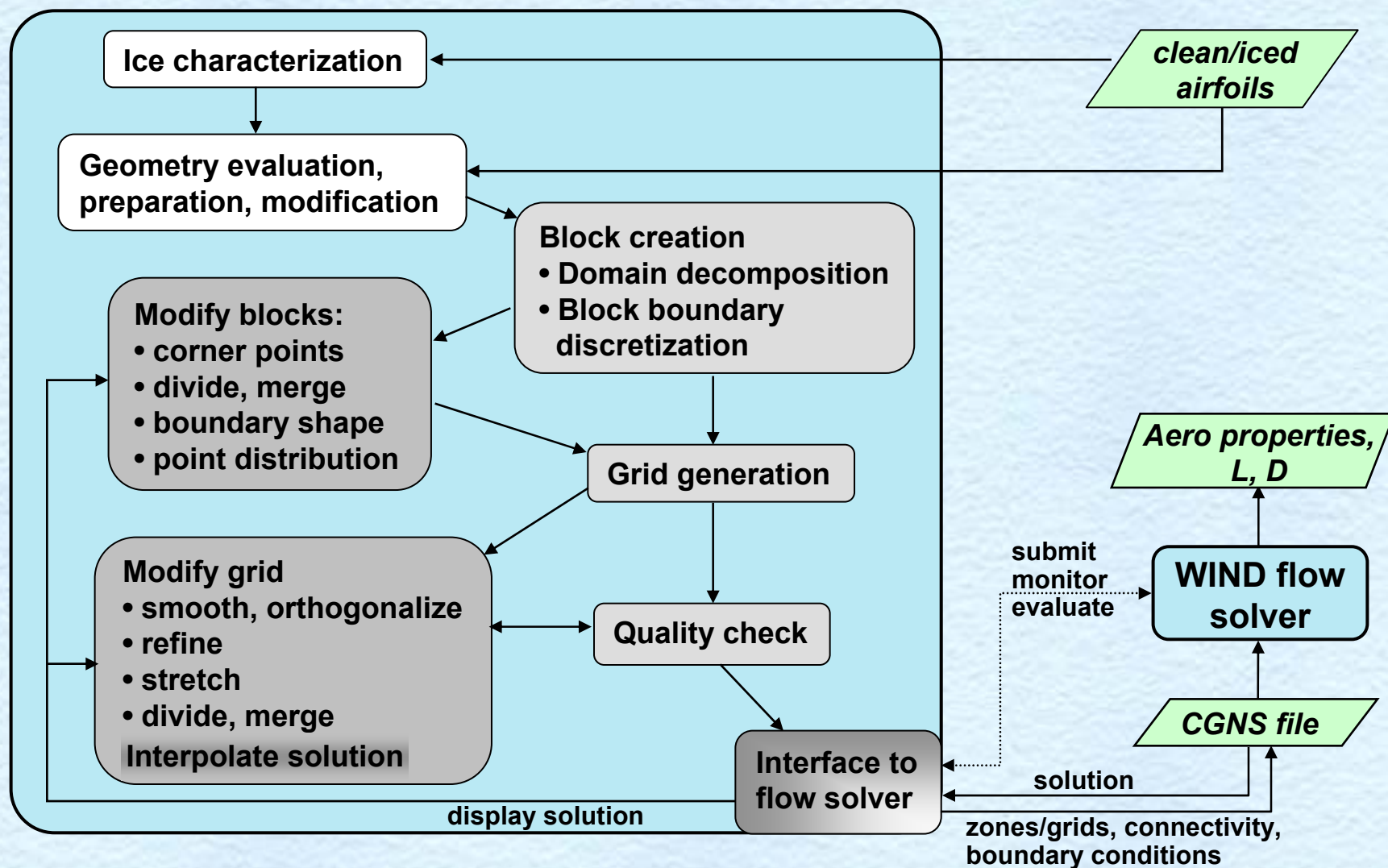
Concluding Remarks



Elements of Icing Effects Study (3D/2D)



A Simulation Process (Smagglce 2D)



Issues in 2D: Data Acquisition

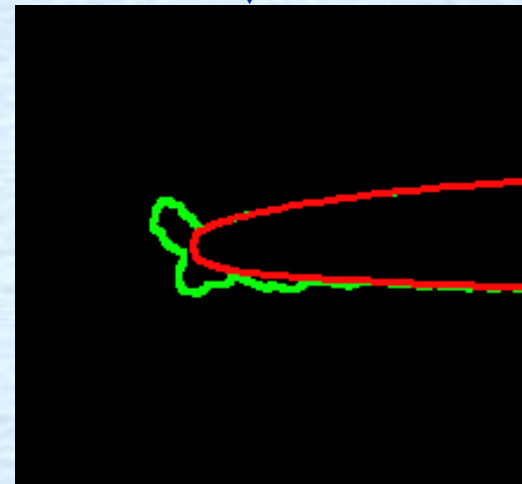
Simulated 3D Ice
(IRT)



LEWICE 2D (Alt)

Trace and Digitize

2D ice

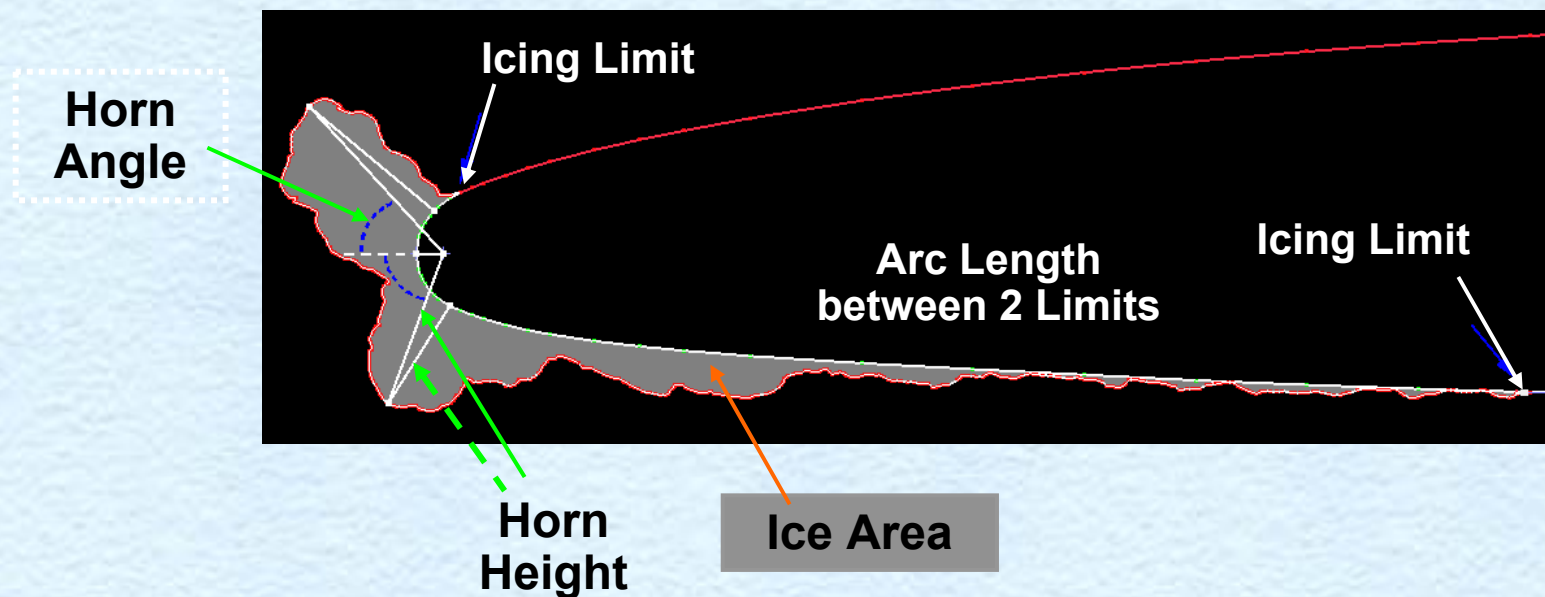


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Issues in 2D: Ice Shape Characterization

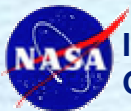
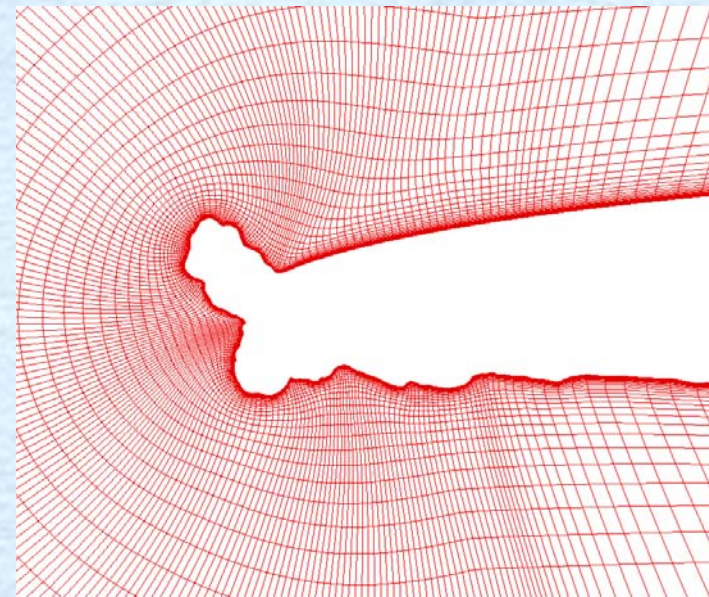
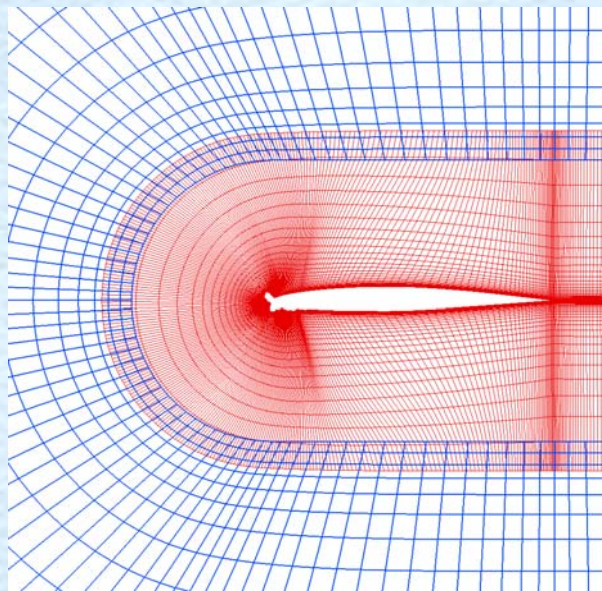
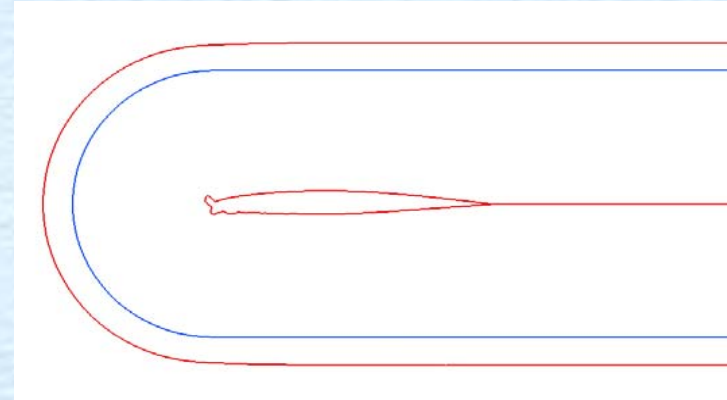
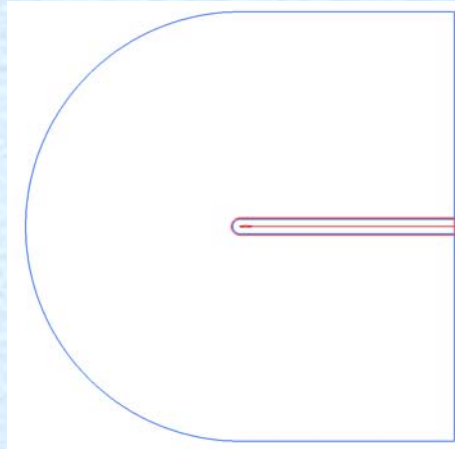
Interactively measure (1) horn height, (2) horn angle, (3) total ice cross sectional area, (4) leading edge minimum thickness, (5) upper and lower icing limits, (6) arc length between two icing limits



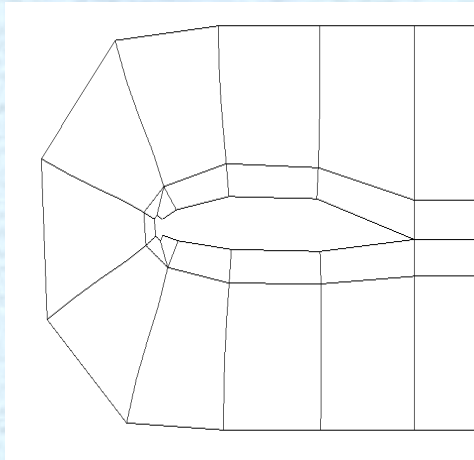
Issues in 2D: Flow Domain, Blocks, Grids

Essential features:

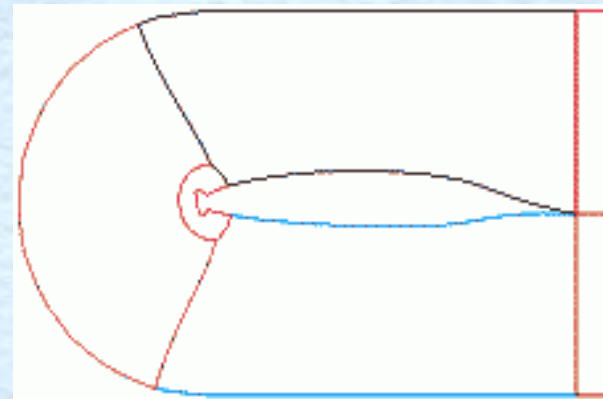
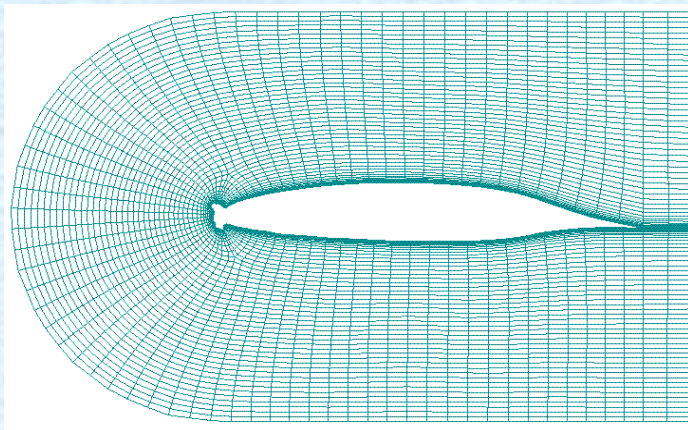
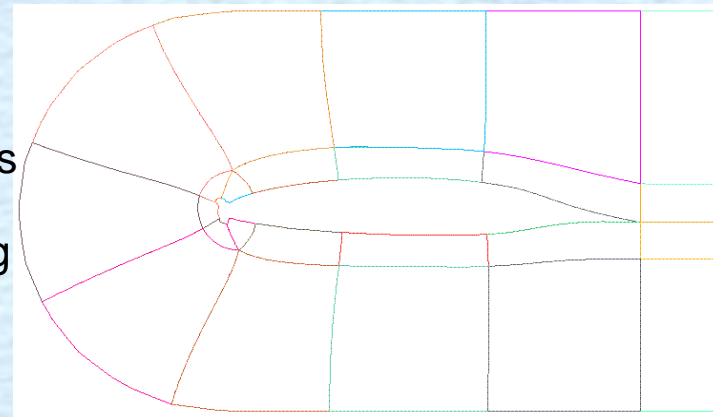
- Both automatic & interactive capability
- Quality control capability



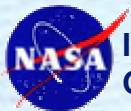
Issues in 2D: Automatic Block Topology Generation and Merging



Radial cuts
&
smoothing



Seek to automate

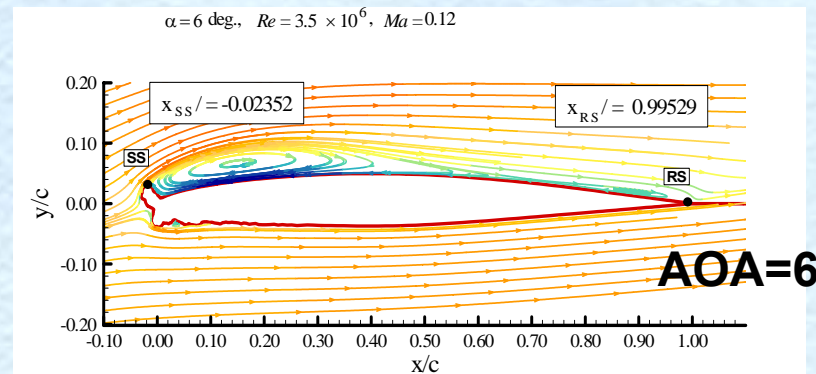
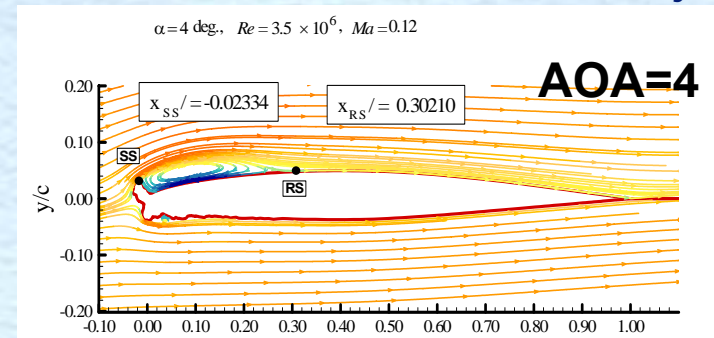
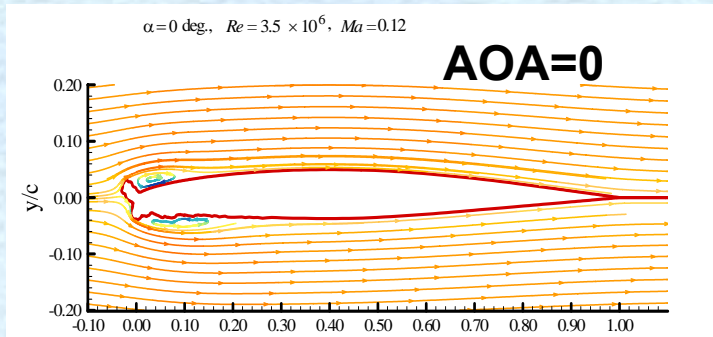


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Issues in 2D: Flow Separation and Reattachment

Streamlines colored by Ma



Test of turbulence models continues.

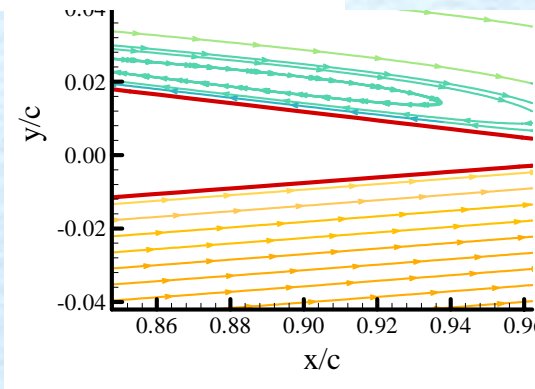
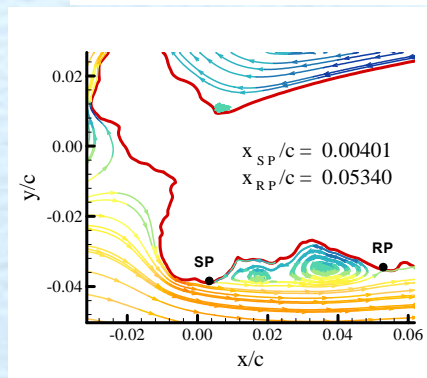
M=0.12

P=20.5psi

Re=3.5x10⁶

AOA=0, 4, 6

EFD & CFD
results are to be
presented at
Reno, 01/2004



Michigan
State
University



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An Interactive Software Toolkit for 2D Ice

- **The current version (Smagglce v1.2) enables users to perform the following tasks:**
 - Detect and correct input errors (detection – automatic)
 - **Measure ice shape characteristics**
 - Perform curve discretization
 - **Provide controlled smoothing of ice surfaces**
 - Create and place computer generated ice on airfoils
 - **Translate and rotate an iced element of a high-lift airfoil**

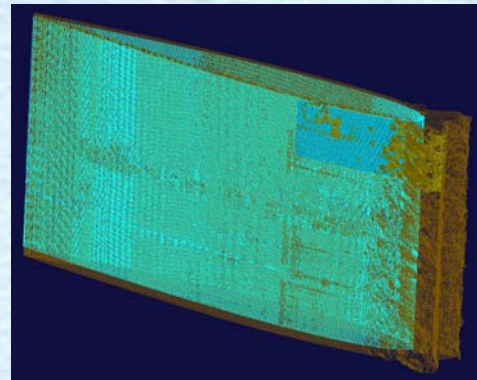
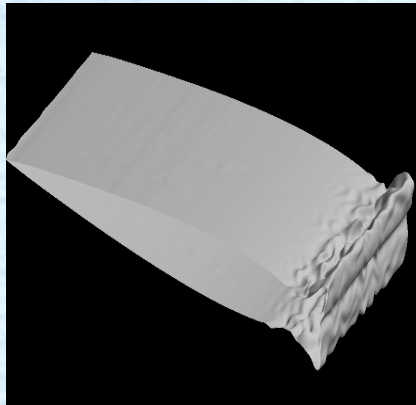


Contact Information for Smagglce v1.2

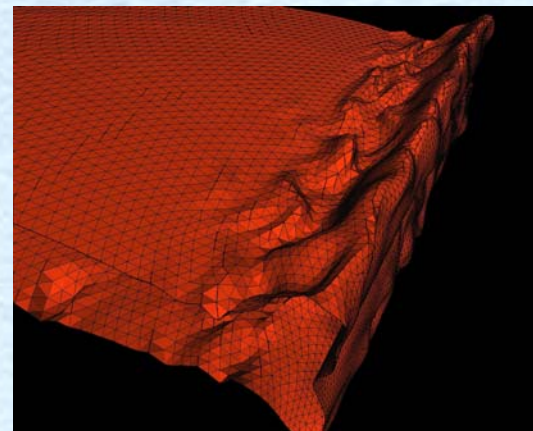
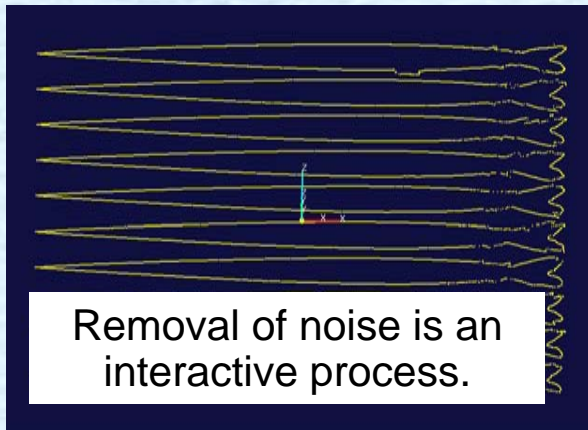
- Available to any U.S. organization upon request at:
<https://technology.grc.nasa.gov/software/>
- There are versions for selected UNIX and Microsoft Windows platforms
- Technical questions are to be directed to:
smaggice@grc.nasa.gov
- For current information, visit:
<http://icebox-esn.grc.nasa.gov/ext/design/smaggice.html>
- A copy of tutorial DVD-video provides an overview and tutorials of the software. It can also be ordered at the above web site.



Issues in 3D: Geometry Acquisition



Point cloud from
3D scan
(J. Van Zante)

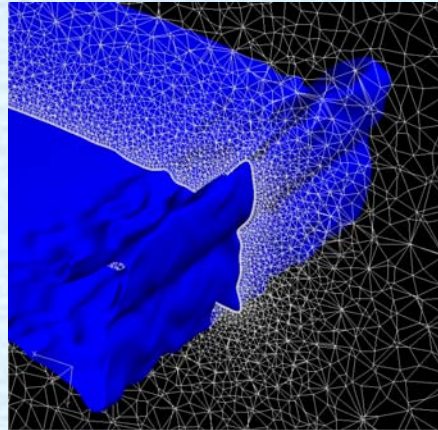
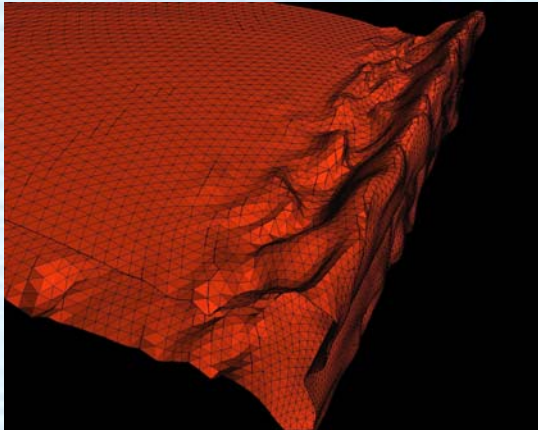


“Surfacer”
Imageware

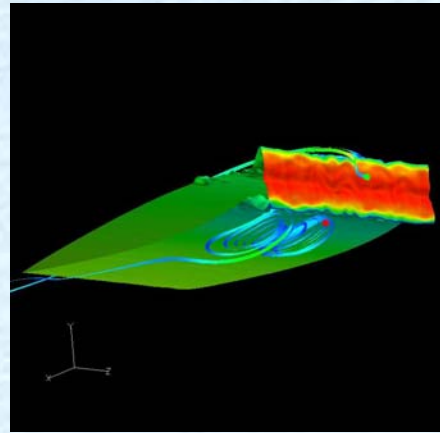
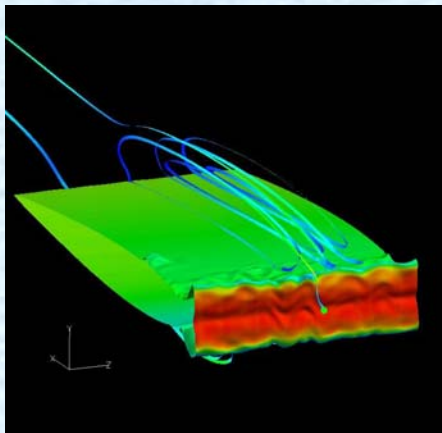
- Under study is a “level-set” based technique to extract surfaces from scanned point cloud data for automation.



Issues in 3D: Grid and Flow Solution



Field grid density
can be controlled
using source lines.



“Cobalt”
MSU

- Ice makes flow complex and computation expensive.

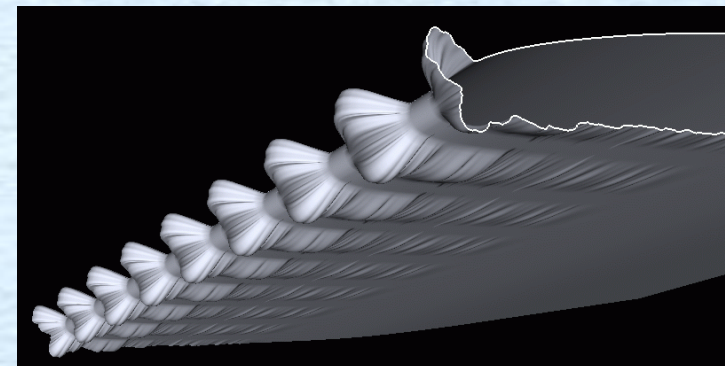
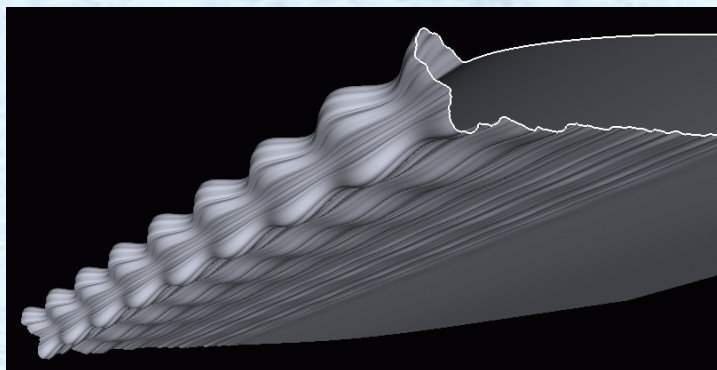
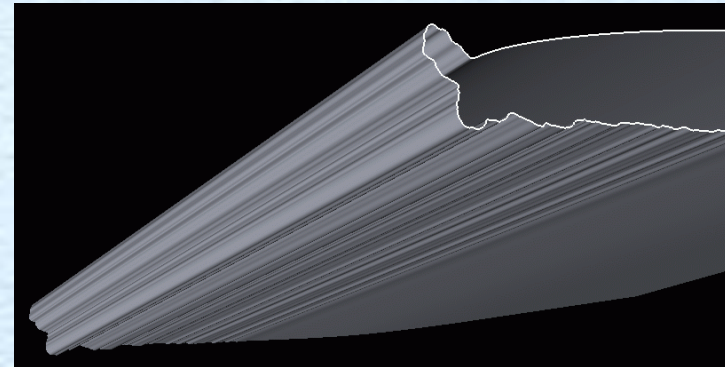
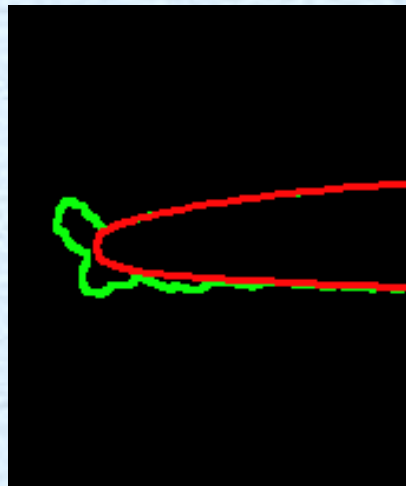
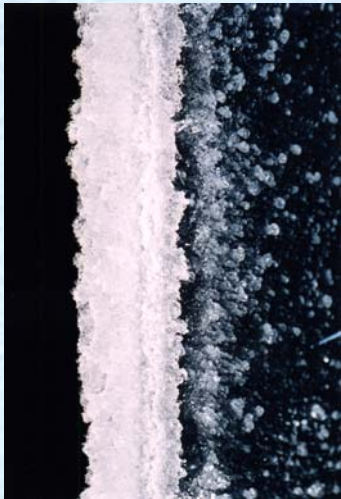


A Hypothesis

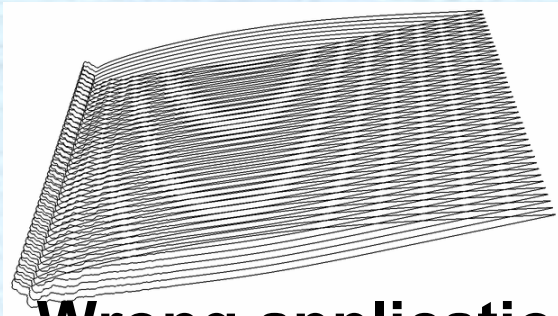
- For any 2D ice shape at a span-wise location of a given natural or simulated 3D ice, new 3D ice shapes can be defined by a blending function in EQ (1), SAE 2003-01-2135. Let the most conservative ice shape be the one that produces the highest lift and drag degradations. Then, among these 3D ice shapes, the extruded ice shape for $\delta = 0$ is *the most conservative* ice shape.
- If the 2D ice shape is *the most conservative* 2D chord-wise cross section of the 3D ice, then the extruded ice shape is *the most conservative* of all 3D ice shapes, including the given natural or simulated ice.



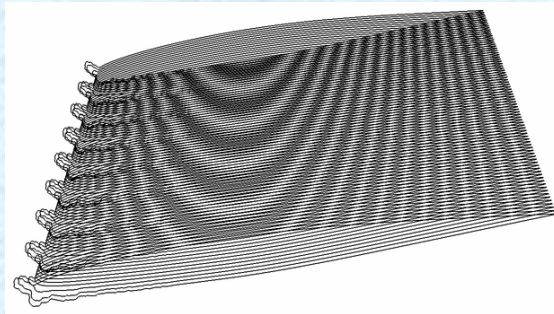
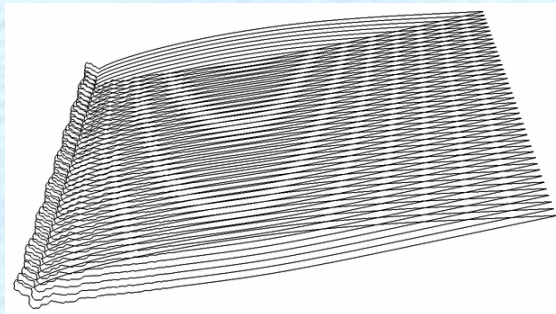
The Most Conservative 3D Ice ($\delta = 0, 0.5, 1.2$, cycle = 8)



The Proposed Hypothesis Applies to Small Sweep Angles



Wrong application!



M. Vargas

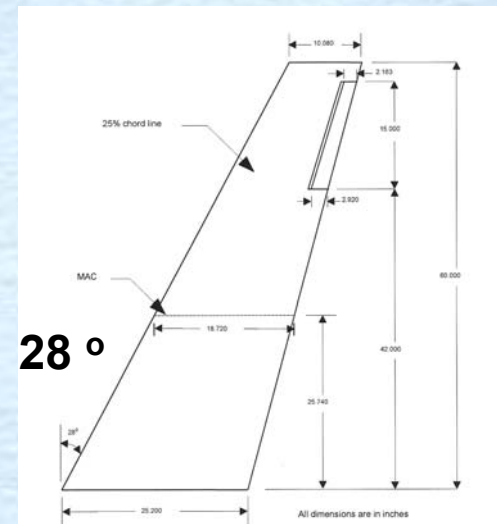


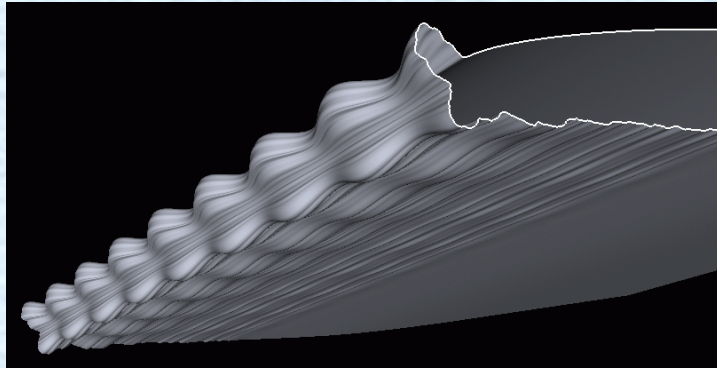
Figure 2. Dimensions and geometry for the GLC-305 airfoil



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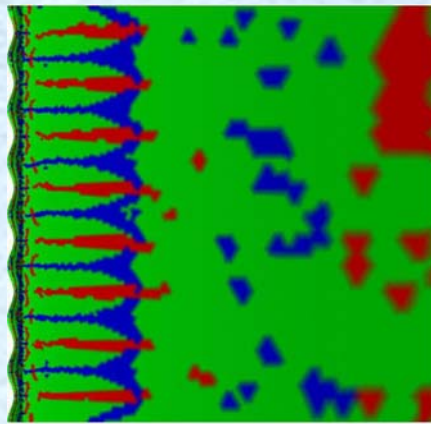
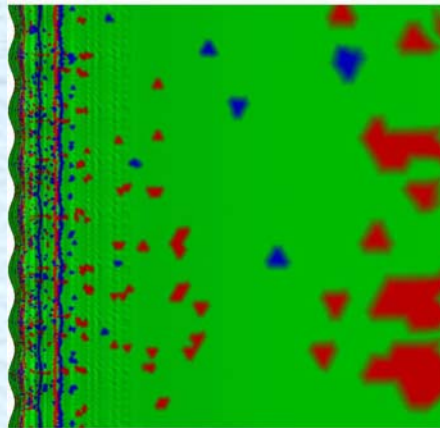
Flow Solution (3D/2D)



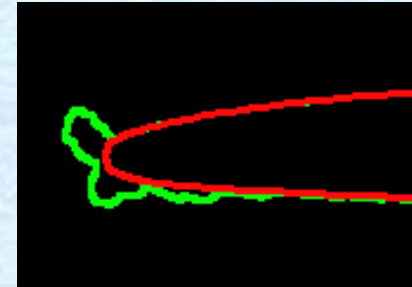
$\delta=0.5, \omega=8$ at $AoA=6^\circ$

Pressure side

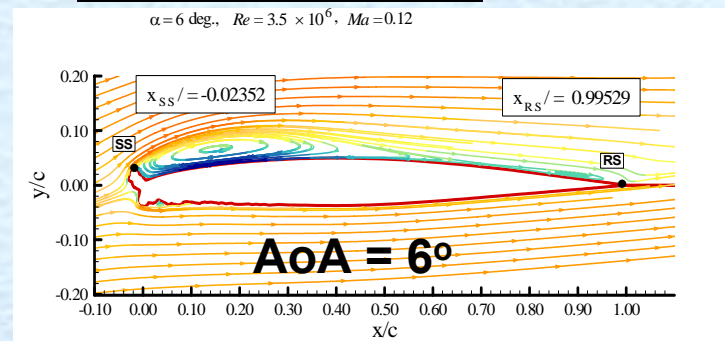
Suction side



Mississippi state Univ.



$\alpha = 6 \text{ deg.}, Re = 3.5 \times 10^6, Ma = 0.12$



Separation & Attachment Lines

Red – separation

Blue - attachment



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Concluding Remarks

2D Numerical Icing-Effects Simulation

- 2D Geometry data acquisition is a routine process.
- **Ice shapes can be easily characterized and prepared for grid generation using Smagglce v1.2.**
- Grid generation and flow simulation are still challenging and expensive for difficult ice shapes, but can be done; the process will get easier with Smagglce v2.0.
- **Turbulence models such as S-A works well for moderate ice, but for the presence of strong vortex, other models such as RSM are under examination.**
- When RANS solutions are not adequate, we need to resort to DES or LES. Both WIND and COBALT have DES capability.
- **2D numerical simulation provides valuable insights to the complex flows with ice. 2D simulation is much cheaper than 3D simulation, yet provides valuable information.**



Concluding Remarks – Cont.

3D Numerical Icing Effects Simulation

- Geometry data acquisition process is not a routine process yet.
- Quality grid generation for wings with complex ice are difficult for both structured and unstructured grid generation.
- Ice geometry definition requires dense surface grid; ice-induced flow is complex. Therefore, computing cost is very high with 3D ice.
- Even steady-flow simulations with ice accretion will be much more expensive computationally than those without ice; DES for unsteady flow will be even more expensive.
- **A Hypothesis for most conservative 3D ice shape is proposed.** Benefits?
 - 2D ice shape is easy to acquire and the extrusion into 3D is easy to perform.
 - Grid generation over the extruded (“the most conservative”) ice is easier than that over most 3D simulated ice geometries.
 - It provides the worst 3D ice shape for the worst 2D ice shape in terms of lift and drag. 2D ice shape characteristics and their effects on performance are understood better than 3D.

